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GLUBOKOVODNYY GAMMA-RADIOMETER I IZMERENIYE RADIOAKTIVNOSTI GLUBINNYKH SLOYEV VODY INDIYSKOGO OKEANA

(The Deep Water Gamma-Radiometer and the Measurement of Radioactivity of Bottom Layers of the Indian Ocean)

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ABSTRACT

The operation of a new instrument known as the deep water gamma-radiometer RAG-1, which can measure radioactivity at great ocean depths, is described. The measurements were conducted from aboard the Soviet survey ship "Vityaz'" in 1959-1960 during its 31st cruise in the Indian Ocean. The RAG-1 radiometer differs substantially from the earlier models in which the recording equipment was placed on shipboard and the radiation detector was submerged. Because of such structure, the depth of measurement was limited to several hundred meters. The new type is built so that the entire recording device together with transmitter can be submerged to great depths. Some typical samples of automatic measurements conducted at depths ranging from 1000 m to 4000 m are tabulated. The numerical values expressing impulses per minute and showing readings of counters are tabulated, compared for various depths, and analyzed with regard to the degree of accuracy. Thus the sensitivity of the radiometer is determined; its threshold being $240\,\gamma$-disintegration (quant)/min/ℓ or $2 \cdot 10^{-10}$ Curie.

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THE DEEP WATER GAMMA-RADIOMETER AND THE MEASUREMENT OF RADIOACTIVITY OF BOTTOM LAYERS OF THE INDIAN OCEAN

The quantity of natural radioactive isotopes in the World Ocean is considerable, constituting approximately 183.83 milliard tons; the total radioactivity of the ocean is about $5 \cdot 10^{11}$ Curie units. This radioactivity is caused mainly by the following isotopes (table I) [5].

Table 1

The Content of Natural Radioactive Isotopes in the Ocean

Isotopes	Concentration, g/cm3	Specific activity, decomp/ cm3/sec	Specific activity, decomp/ ℓ/min	General quantity of isotope in ocean X10^6, t	General activity in ocean X10^3, Curie units
K^{40}	$4.5 \cdot 10^{-8}$	$1.2 \cdot 10^{-2}$	720	63 000	460 000
Rb^{87}	$84 \cdot 10^{-8}$	$2.2 \cdot 10^{-4}$	1.3	118 000	8400
U^{238}	$2.0 \cdot 10^{-9}$	$1 \cdot 10^{-4}$	6	2800	3800
U^{235}	$1.5 \cdot 10^{-11}$	$3 \cdot 10^{-6}$	0.18	21	100
Th^{232}	$1 \cdot 10^{-11}$	$2 \cdot 10^{-7}$	0.012	14	8
Ra^{226}	$3 \cdot 10^{-16}$	$3 \cdot 10^{-5}$	1.8	$4.2 \cdot 10^{-4}$	1100

In addition, the natural radioactive isotopes of a cosmic origin, such as C^{14}, H^3, Be^{10}, Be^7, Na^{22}, P^{32}, P^{30}, S^{35}, may be found in sea water, but their contribution to the overall activity in the ocean is small.

Thus, the main isotope creating a noticeable radioactivity of the ocean, which is by itself small — namely, hundreds of times smaller than the radioactivity of granite and sedimentary rocks — is K^{40} $T_{1/2} = 1.31 \cdot 10$ years, $\beta(88\%) = 1.32$ Mev (Million electron volts), $\gamma(12\%) = 1.46$ Mev. One can assume that the distribution of K^{40} is rather uniform in the World Ocean, which follows from the known ratio of potassium content (stable) to the magnitude of salinity in sea water [6]

$$\frac{K}{C\ell} = 0.020.$$

The salinity of the World Ocean, as is known, varies little (34-35°/oo).

Lately, in connection with the tests of nuclear armaments and the increase of the practical application of atomic energy, a considerable quantity of radioactive isotope debris is found in the World Ocean. It is assumed [9] that on the basis of the locations, where the greatest nuclear detonations have occurred, and considering the relative magnitude of the land and sea areas, 90°/o of the radioactive wastes are discharged in the ocean where they propagate all over its area. The radioactivity remaining after nuclear detonations is due mainly to the isotopes pointed out in table 2. In addition to these isotopes, their daughter products, such as Y^{90}, Ru, Pr, may be present in the ocean; the latter of them being γ-radiators.

We shall not present a detailed analysis of the pollution of the ocean by radioisotopes; let us point out only one of the conclusions, namely, that the pollution of the ocean is not localized because the radioisotopes can be transferred by ocean currents and air mass movements to great distances from the place of nuclear detonation. Thus, for instance, Sr^{90} was found (of course, in small quantities, of the order of 0.60 decomp/min/ℓ) in the water of the North Atlantic Ocean [7]; in addition, radioactive rare-earth elements [8] were found in the same area. Artificial radioactivity can be recorded to distances of 16,000 km from the place of detonation [9].

Table 2

The Durable Radioisotopes Determining the Pollution of the Ocean

Name	$T_{1/2}$	γ, Mev
Kr^{85}	10.27 years	0.1495 0.540
Rb^{87}	$6.1 \cdot 10^{10}$ years	0.394
Sr^{90}	19.9 "	
Ru^{106}	290 days	
Cs^{137}	33 years	0.66
Ce^{144}	282 days	
Pr^{147}	2.26 years	
Eu^{155}	1.7 "	
Co^{60}	4.95 "	1.17 1.33
Mn^{54}	310 days	0.83

A number of Japanese studies [10] have established that at a distance of almost 2500 km from the Bikini Atoll, where the atomic weapons had been tested, the activity of sea water was considerable, reaching 1830 decomp/min/ℓ. A huge "cloud" of radioactive water was transferred in a northwestward direction by currents, one of which was disclosed owing to the presence of this "cloud".

The distribution of radioactivity in sea water is, as a rule, investigated by radiochemical methods, whereby the measurements are preceded by the concentration and chemical separation of radioisotopes. In addition to this accurate and sensitive but rather difficult method, attempts were made to measure directly the increased radioactivity of sea water. Thus, a number of instruments had been developed by the Oceanographic Institute of the U.S.A [5] with a view to determining the radioactivity of the rising level in the upper water layer. The detectors of these instruments — mainly, the gas calculators — were connected by means of cables with the recording devices on shipboard. These instruments made possible the determination of the γ-background over the water surface and at a small depth from a moving ship. B. A. Nelepo [4] used a radiometer with scintillating detectors for measuring the radioactivity of Antarctic waters. The measurements were carried out at depths to 150 m, whereby the light impulses could be roughly discriminated by the energy of computer (PS-10000 "Floks") placed aboard the survey ship "Ob'". V. N. Lavrenchik and G. N. Sofiyev [3] conducted several measurements of the radioactivity of Indian Ocean water to depths of 1000 m; as a result, several radiation spectra were obtained on the 50-channel analyzer.

In all of the mentioned cases, the small length of conducting cable limited the possibility of measurements at great depths.

However, a direct and rapid measurement of radioactivity at depths exceeding 1000 m is of great interest for clarifying both the character of propagation of radioactivity in the ocean, and a number of hydrological problems (boundaries and directions of currents, origin of water masses, etc.).

Of especial importance is the elucidation of the problem on the behavior of radioactivity in the deep ocean depressions because at the present time, in connection with the problem of the burial of radioactive wastes, a motion to bury them at the greatest ocean depths has been raised. /336

Two contradictory views have been expressed on the matter. The Soviet scientists [2], on the basis of a number of hydrochemical and hydrological data, concluded that the waters in depressions are rapidly replaced and that noticeable currents exist along the deep trenches, which must lead to a rapid transfer of the radioactive wastes to other areas. Thus, the burial and conservation of the wastes becomes, naturally, impossible. The American scientists hold a contrary viewpoint. Only a direct investigation of the propagation of radioisotopes at great depths may give the final answer to the question.

However, we did not have instruments for measuring the radioactivity at great depths.

This study describes the deep water radiometer RAG-1 and lists some of the data on radioactivity obtained at great depths of the Indian Ocean. The work was carried out in 1959-1960 in Moscow and from aboard the survey ship "Vityaz'" during its 31st cruise.

The operation of the few submarine radiometers discussed in oceanographic literature can be characterized as follows: only the radiation detector is submerged by means of cable to a given depth, while the entire recording equipment is located aboard ship.

The advantages of such arrangements are as follows: a) it is possible to obtain the radiation spectrum (in the case of scintillating detector); b) to measure and examine continually the operation of instruments; c) the measurements at small depths are convenient and simple.

However, such designs of instruments have also certain deficiencies: the operation becomes complicated when using a long cable, and unreliable at great pressures; also, the measurements become cumbersome because the use of long cable creates the need for a special deep water impeller (GOL or trawling type), the operation of which is associated with time losses; further, if the use of a long cable would be scientifically feasible only for the rendering of radiation spectrum (but not for a simple calculation of radioactivity), its application will lead to further complications of the recording apparatus (multichannel analyzer).

But, also another design is possible: the entire recording device together with transmitter can be built so that it can automatically operate in deeper water layers.

In this case, the radiometer can be submerged by the cable of the usual hydrological winch ("Okean" type), which does not limit the depth of operation; the absence of the lead of cable increases the guarantee of hermetical status of the instrument; also, it increases the freedom from interference and the pickup on transfer cable is eliminated; thus, the utilization is simplified.

The deficiencies of this type of instrument are as follows: it is impossible to control the operation of the apparatus in the deep layers; information is delayed until the radiometer is taken out of the water.

However, the advantages of this apparatus for the measurement of radioactivity at great depths were so obvious, that they determined the construction of the mentioned radiometer RAG-1.

The technical problem — namely, the creation of a sensitive, dependable, and simple apparatus, which can automatically record the radioactivity at maximum ocean depths — was solved.

The radiotechnical device of this deep water radiometer fulfills the following requirements: it is stable as regards temperature, moisture, corrosion; further, it is not sensitive to blows that may occur when submerging the apparatus; it operates within a temperature range from +40° to -5°; the battery operation is stable for a period not less than 5 hours and does not require adjustment; the size of the deep water radiometer must admit its placement into a firm casing.

A scheme of the chassis of the radiotechnical portion of the deep water radiometer, which has been constructed with a view to accounting for the above mentioned requirements, is presented in fig. 1; a diagram and general form of the apparatus are shown in fig. 2 and 3.

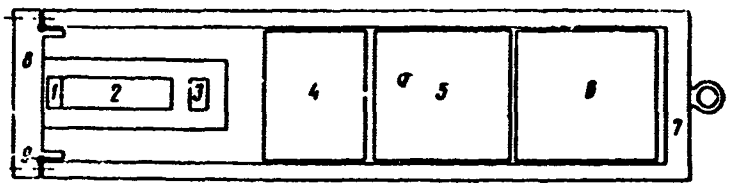

Fig. 1. A scheme of the chassis and assemblage of a deep water radiometer.

1—scintillating crystal; 2—FEU; 3—amplifier and discriminator; 4—feeder; 5—calculating and computing device; 6—chassis of calculators; 7—the steel body; 8—frontal flange; 9—compaction.

A NaI crystal was used in the operation of the deep water radiometer, its size being 30 x 10 mm (1.1 x 8 in x .3 x 9 in).

The photoelectronic multiplier of the FEU-29 type is fed by a sectionalized dry battery having a full charge of 1200 v. Usually, the potential of FEU is about 1000 v, whereby the sensitivity of FEU (according to the accompanying papers) equals 100 a/*l*m (ampere lumen. Tr.); the FEU operates in a spectrometric regime. A complete resistance of the divider is about 100 mohm (megohms), because of which the current used is not strong and the operation time is determined solely by the time of battery storage. The impulses from the anode FEU reach the double emitter-repeater assembled on diffusional transistors P-402, where $R_{vx} = 300$ kohm (kilohms) and $S_{vx} = 50$ pF. With the anode resistance of FEU equalling 200 kohm, the constant of loading time of FEU equals 6 microseconds.

The main requirements for the amplifier of a deep water radiometer are its economy and stable operation. These properties determined the selection of a scheme having transistors with feedback and thermal compensation. The amplifier is assembled of transistors with various types of conductivity. For the amplification of signals with negative polarity, the germanium triodes P-15 (r — p — r) are used; but for the amplification of signals with positive polarity, the germanium triodes P-103 (p — r — p) are used. Such an amplification system has a better stability. The amplification coefficient of the first two cascades before the discriminator on diode D-2E is about 100, which guarantees the calculation of impulses exceeding 16 mv when the voltage of the discriminator is 1.6 v. Both of the cascades are capable of feedback and thermal stabilization by introducing resistances into the emitter circuits and dividers into the base circuits. A 2-x cascade amplifier whose intensification coefficient is of the order of 800 follows the discriminator. The amplifier is not thermally stabilized. The transformator having a transforming coefficient 1 : 6 serves as a load to the second cascade. The polarity of impulse emanating from the amplifier is positive, its duration being 100 microsec. This impulse is transferred to a normalizer, which is mounted on a cold-cathode thyratron MTX-90. From the normalizer the impulses having 200 sec duration and 40 v amplitude are transferred to the calculator.

The introduction of the calculator into the model of a deep water radiometer makes it possible to measure the radioactivity of ocean in a wide range of activity.

The choices of calculations are as follows: x1, x2, x8, x16 or x32. /339
This makes the errors of uncalculated impulses considerably smaller than statistical errors. In addition, this calculator enables us to calibrate the radiometer by a standard of relatively high activity. The calculating scheme consists of five identical cascades of calculating x2. Two MTX-90 lamps operate in each of the cascades. The counting time for periodic impulses equals 2 msec. The calculation scheme operates on the triggering cascade of a mechanical computer, which is also mounted on the MTX-90. This cascade secures the counting of impulses to 40 imp/sec. It must be stated that the MTX-90 is very sensitive to changes in the feeding operation, which must lie within the range of 125-135 v. The determination of the exact value of potential is made by alternate resistance $R_{10} = 47$ kohm.

The recording device of the radiometer represents a chassis consisting of 10 counters known as SB-100 M, which are connected with the calculating scheme in a definite sequence by a program mechanism.

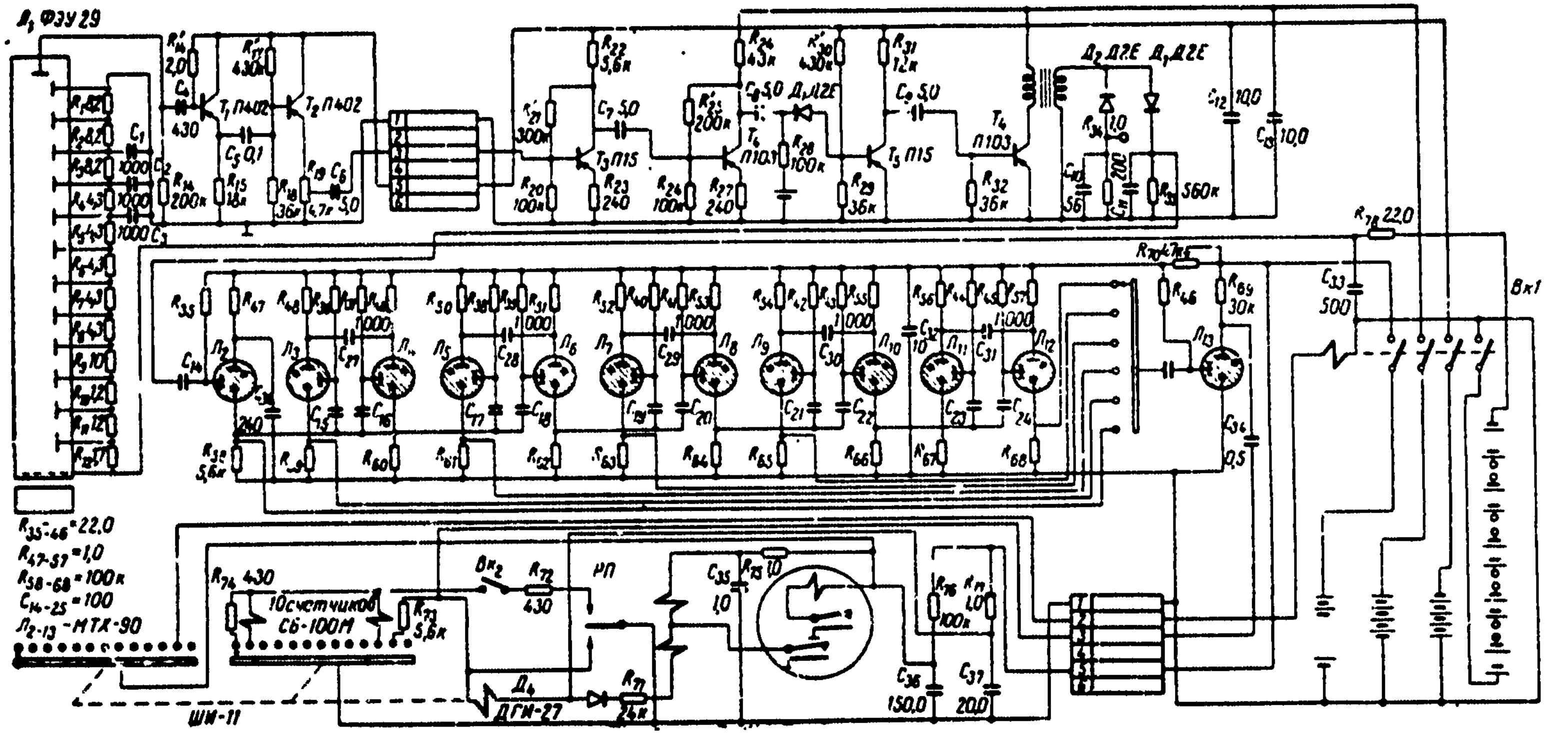

Fig. 2. Radiotechnical scheme of a deep water radiometer.

Key. Bottom, left: 10 calculators SB-100 M.

The program mechanism includes electric automobile timers, a polarized relay device and a step-by-step switch ShI-11. The contacts of electric timers are made of Ø 0.1 mm platinum wire, which are fastened to a dented wheel of timers making one revolution in 10 min, and to a movable contact of the body of the timers. The timer contacts lock the feeding of coils of a polarized relay mechanism, the operation of which causes the shifting of the step-by-step switch to the subsequent position and a corresponding shifting of the calculator. The period of operation of the program mechanism equals 10 min ±0.2 sec. It is possible to operate in one of the two regimes: the shifting of calculators each 10 min and the shifting with 10 min intermissions between measurements. Ten minutes elapse between the switching of feeders and the switching of the first calculator. When the step-by-step switch is shifted into the latter, 11th position, the electromagnetic switch-off VK-1 begins to operate and the radiometer scheme is completely stopped.

Fig. 5. Part of the radiometer casing (time relay, step-by-step switch, the chassis of mechanical calculators).

The feeder mechanism consists of four dry batteries. The high voltage battery is assembled of flat dry cell GB-100 batteries, divided into five sections in order to diminish its discharge. The battery capacity equals 0.05 a/h, which lasts for 5000 hours if the load resistance is 100 mohm. The feeder and automatic operation battery of the calculating mechanism consists of flat dry BAS-G-60-L-1.3 batteries, with a capacity of 1.3 a/h if the potential is 150 v. The calculation scheme uses 0.4 ma, the triggering cascade of mechanical counter uses 0.2 ma when counting 2 imp/sec, the program mechanism utilizing on the average 0.2 ma. Thus, the batteries operate for 1600 hours. The batteries feeding the amplifier (+6 v and -6 v) consist of flat dry BAS-G-80-U-2.1 batteries with a capacity of 2.1 a/h. Both of the batteries use 1 ma of current, so that the operation period equals 2100 hours. Thus, the operation time of a deep water radiometer consisting of one set of batteries is practically limited only by the operation time of the batteries. This is of great significance, because during the time of one measurement (200 min) the feeding charges

cannot change substantially. Besides, the absence of the need for frequent changes of batteries adds to the advantages in the operation of the radiometer.

In order to investigate the possibility of measuring radioactivity of sea water, the terphenyl crystal of the radiometer was lowered several times. The light of the crystal passed through a special light-conductor, mounted on the flange. As a result of the experiment, it was established that with the increase in pressure with depth, the optical contact between the crystal and the light-conductor is interrupted.

The body of the radiometer is made of a piece of steel pipe; its $\phi_{ext} = 200$ mm, $\phi_{int} = 140$ mm, length is 1400 mm. The weight of the whole radiometer is 200 kg (440 lbs). The upper flange with a ring for fastening of cable is welded to the body. The lower flange is removable. A brass case is fastened to the flange; all the parts of the radiometer are, in turn, fastened to the brass case. The interchassis connectors are made by six contact joints of "A" type. The flange is fastened to the body by 8 tacks known as C-10, which are made of stainless steel. The hermetical contact is secured by a self-sealing gasket, designed by the IOAN (Inst. of Oceanology of the Academy of Sciences of USSR) and calculated to withstand a pressure of 1000 atm.

Calibration of the instrument. Because the theoretical calculation of the effectiveness of the radiometer appeared to be complex, the instrument was first calibrated on an experimental basis by submerging it into water with a known specific activity. As a consequence, the value of impulses of the radiometer was determined, i.e. the relationship between the number of recorded impulses and the number of particles causing them was introduced. Because all of the radiochemical determinations of radioactivity in sea water are defined by fractions of Curie per liter (or by the number of decompositions per liter), the impulse value of our radiometer was also defined by the number of decompositions per liter in a minute.

Simultaneously, the natural background of the instrument was determined. The calibration of the radiometer was made in a sufficiently large round water basin ($\phi = 5.15$ m, $H = 4$ m) whose volume was 80.2 m^3, and which was covered by concrete. Because there was a need for lengthy measurements and a continuing flow of information, a cable was introduced into the radiometer (for compaction) for the feeding of the instrument and the transfer of impulses. The high voltage feeding and recording the impulses was carried out at PS-10,000. It is interesting to list a few data relative to the submergence of the radiometer into a basin filled with fresh water.

At one meter from the earth's surface around the basin	368	imp/min
In empty basin	324	" "
In basin filled with water	66.0	" "

Thus, a lowering of the background by a water layer 2 1/2 m thick and the concrete cover was observed. In order to eliminate the radiation effect of the concrete, the radiometer was placed at a distance of 1.5 m from the walls and the bottom of the basin.

The K^{42} isotope was used for calibration. This was determined both by the brief period of the half-life of the isotope (12.44 hours) and by the character of radiation, which was near the radiation of the natural K^{40}/K^{42}—1.51 mev, K^{40}—1.46 mev, as well as by the simplicity of procedure (by n, γ-reaction).

The exposure to radiation of 356 mg of KNO_3 yielded the activity of 37.8 m Curie[1]. The value of this activity was determined by comparing 1/500 of activity (0.05 mℓ of solution) with the Co-standard in a counting setup. Because the radiometer has been designed for measuring radiation, the specific activity was determined in γ-disintegrations (min/ℓ) by assuming that the amount of γ-disintegrations equals 25°/o for the decomposition of K^{42}. /341

The salt, containing K^{42}, was dissolved in 25 mℓ of water and poured through a funnel down a glass tube on the bottom of a basin filled with water. Afterwards, the flask and tube were carefully cleansed by a solution of tartaric acid and a large quantity of water.

A uniform distribution of the introduced activity throughout the basin was achieved by energetic intermixing of water by a spray of compressed gas (nitrogen). The rapid rate of intermixing is confirmed by the fact that a continued increase in the count was not observed in 5 to 6 min.

The measurements were conducted in six days, which is the time for a complete decomposition of the isotope.

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[1] The P/x purity of compound was determined on the basis of half-life (at calibration) and the γ-spectrum obtained on a 100-channel analyzer.

The results are listed in table 3.

Table 3

Calibration of Radiometer

Time		Specific activity, γ-disintegr/min/ℓ	Reading of instrument, imp/min	Value of impulse, γ-disintegr/min/ℓ
Date	Hour			
Nov. 25	18.00	215 000	5205	41.4
" 26	14.20	65 400	1984	32.9
" 27	15.10	16 340	498	32.8
" 28	16.00	4080	140	29.1
" 29	16.50	1020	32	31.8
" 30	14.00	311	11	28.3
" 1	12.00	39	0	—

Except for the first hours of measurements, when the excessive activity caused miscalculations in the setting designed for small speeds of impulses, the magnitudes of impulses appeared to have nearly equal values. Thus, it was established that one impulse recorded by the RAG-1 corresponded to 31 γ-disintegr/min/ℓ or $0.343 \cdot 10^{-10}$ Curie/ℓ for K^{42} or $0.725 \cdot 10^{-10}$ Curie/ℓ for K^{40}.

<u>The radioactivity of ocean bottom waters</u> was measured in 1959-1960 during the 31st cruise of the survey ship "Vityaz'" in the Indian Ocean.

The work method can be reduced to the following:

1. <u>The plotting of the graph of measurements</u>. The radiometer admits two types of switches of mechanical counters — subsequently (regime I) or with ten minute intervals (regime II). The choice of switch regime is determined by a concrete problem. In order to gain results with a greater statistical accuracy at one depth level, the subsequent switch of counters appeared to be rational (regime I). If, however, the measurements are carried out at various depths, the ten-minute interval between switches is necessary for the taking of the radiometer to the given depth (regime II). The regimes I and II differ substantially by the time used for a complete measurement: 100 minutes are needed when using regime I and 190 minutes when using regime II.

Therefore, sometimes, for the sake of time economy, the measurements at various depths were made by regime I — two at each depth level. Further, of course, not all of the ten counters were used because part of them were operating during the lifting and lowering of the radiometer.

Let us cite a few examples of the operation regime of the radiometer: the Roman figures denote the number of counters by which the data of measurements at each depth were recorded; dashes (—) denote the displacement of radiometer from one depth level to the other:

	St. 4707		St. 4712		St. 4718	
Shipboard		I	—		—	
"		II	200 m	I	100 m	I
"		III	—	II	—	
	100 m	IV	1014 m	III	1002 m	II
	" "	V	1014 "	IV	—	
	" "	VI	—	V	2004 m	III
	" "	VII	2500 m	VI	—	
	" "	VIII	2500 "	VII	3007 m	IV
	—	IX	—	VIII	—	
Shipboard		X	4020 m	IX	3471 m	V
			4020 m	X	—	
			—		3007 m	VI
					—	
					2004 m	VII etc.

2. <u>The displacement of radiometer from one depth level to the other</u> was carried out strictly in accordance with the time: simultaneously with the triggering of relay time of the radiometer the second meter was switched on aboard the ship. The speed of lifting and lowering of the instrument was accurately determined. Thus, for instance, 1000 m of the lowering of radiometer by the fourth speed of the "Okean" winch was accomplished in 4.5 to 5 min; whereas 1000 m of the lifting of radiometer by the third speed took 6.7 to 7 min. Prior to each displacement, the radiometer was held at the depth that had been measured for 1 to 2 min.

The usual displacements of the radiometer ranged from 100 to 2000 m, because these distances were made in 8 to 9 min, which did not involve losses in the readings of one of the counters.

3. The instrument was calibrated prior to each series of measurements, i.e. prior to each submergence. The selection of identical voltage transferred to the FEU was controlled by the counting of calibrator (Co-60, 0.56 m Curie) with an accuracy range of 1°/₀. Also the calculating scheme of the instrument 1 : 16 was switched on. The calibration was made in a laboratory for an hour, immediately before and after the lowering of the instrument. Such a calibration made it possible to compare the data of measurements at various stations.

4. The instrument was made hermetic aboard the ship. The case with the apparatus was brought from the laboratory and installed in the body of the radiometer, which was covered by a flange with gasket.

Taking into consideration the high degree of air moisture (to 98°/₀ at temperature 32°) and the possibility of moisture condensation on the inner parts of the instrument when it is submerged into the cold layers of water, a drying holder with silica gel was placed into the instrument before it was hermetically closed. The high moisture also determined the need for the keeping of the instrument aboard the ship after the measurements are completed; because, if the hermetical status of the instrument is interrupted, a dangerous moistening of the equipment may ensue.

5. The readings of mechanical counters of the radiometer were taken in the laboratory.

6. The RAG-1 radiometer was handled by a hydrological winch "Okean"; the diameters of its cables were 5.6 and 4.5 mm. Two men were in charge of the radiometer, one being the operator of the winch. When calibrating the true depth of measurements, the inclination angle of the cable was accounted for.

It was possible to coordinate the operation of the radiometer at great depths with the simultaneous work of other deep water instruments (bottom grab, trawl) from the same shipboard. The measurements at depths to 220 m were carried out with a simultaneous operation of instruments on the opposite side of the shipboard, which made possible a considerable economy of time.

The maximum sea state during the measurements was 5. /344

Thus, the RAG-1 radiometer measured the radioactivity in the central and northern regions of the Indian Ocean.

The measurement data are listed in table 4 (for station locations see [1]).

Table 4

The Data of R/A Measurements in the Indian Ocean

Station	Depth, m	Readings of counters	Scaling	Time of change, min	I, imp/min	Station	Depth, m	Readings of counters	Scaling	Time of change, min	I, imp/min
4603*	1000	378			37,8		200	392	1	10	39,2
	1000	387			38,7		100	392			39,2
	2000	367	1	10	36,7		50	445			44,5
	4000	331			33,1		10	451			45,1
	4000	357			35,7		0	702			70,2
	4000	320			32,0	4604	50	37			59
4609*	4000	405			40,5		200	39			62
	4000	450			45,0		200	40	16	10	64
	3000	462	1	10	46,2		50	38			61
	3000	455			45,5	4697	200	611			61,4
	2000	414			41,4		1000	594			59,4
	2000	427			42,7		1000	592			59,2
4609*	200	376			37,6		2500	632	1	10	63,2
	200	391			39,1		2500	649			64,9
	100	415	1	10	41,5		4000	580			58,0
	0	727			72,7		4000	621			62,1
	0	772			77,2	4701	100	601			60,1
	0	791			79,1		100	573			57,3
	0	740			74,0		100	597			59,7
4614*	10	491			49,1		100	608	1	10	60,8
	50	454			45,4		100	637			63,7
	100	444			44,4		100	607			60,7
	200	422			42,2		100	590			59,0

*The measurements at stations 4603, 4609 and 4614 were conducted with a different effectiveness of counting in comparison with other stations.

Table 4 (cont.)

Station	Depth	Readings of counters	Scaling	Time of change, min	I, imp/min	Station	Depth	Readings of counters	Scaling	Time of change, min	I, imp/min
4708	In labo-ratory	1220			122,0		3000	145			58,0
							2000	149			59,6
	0	946			94,8		1000	150			60,0
	100	589			58,9		100	152			60,8
	100	592	1	10	59,2		0	292			116,9
	100	659			65,9	4720	100	151			60,4
	100	542			54.2		100	146			58,4
	100	560			56,0		200	150			60,0
	0	1051			105,1		200	156			62,4
4712	200	137			54,9		100	153	4	10	61,2
	1000	149			59,6		100	161			64,4
	2500	150	4	10	62,0		200	153			61,2
	2500	153			61,2	4721	100	136			54,4
	4020	147			58,8		1000	152			60,8
	4020	146			58,4		2100	131	4	10	52,4
4717	20	40			64		3150	139			55,6
	214	37			59		4270 bottom	537			215,5
	214	37	16	10	61	4721	100	144			57,6
	100	38			62		1000	140			56,0
	100	39			62		2100	140			56,0
	20	41			65		3150	130	4	10	55,2
4718	100	147			58,8		4000	142			56,8
	1000	145			58,0		3300	145			58,0
	2000	145			58,0		1000	136			54,4
	3000	141			56,4		0	283			113,2
	3500	141	4	10	56,4						

Prior to the evaluation of the data, let us remember that the impulse value of this radiometer (the coefficient of counting efficiency) is $3.24\,^{0}/_{0}$; 1 impulse corresponds to 31 γ-disintegrations/min/ℓ.

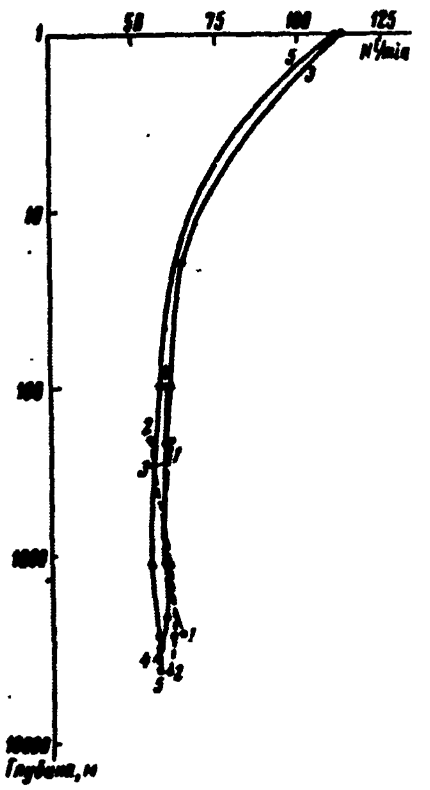

Fig. 4. Radiometer readings with depth (depths given in logarithmic scale).

Y-axis: depth.

As was pointed out, the potassium content in sea water is rather constant, depending on the overall salinity which varies little. Thus, for instance, at one of the oceanographic stations (no. 4712), where the measurements were conducted, the salinity values chang i with depth as follows:

0	104 м	1000 м	2000 м	3665 м
35,46‰	36,5‰	35,3‰	34,87‰	34,75‰

i.e. the difference is about $4\,^{0}/_{0}$.

For sea water, the specific activity of which, based on K^{40}, was 720 disintegration/min/ℓ or 86.4 γ-disintegr/min/ℓ, the fluctuations constituted about 3 γ-disintegration/min/ℓ, which will not be recorded by the radiometer at the given impulse value; thus the natural background of sea water, based on K^{40}, can be considered to be constant.

In such a case, on the basis of the impulse value and the mean magnitude of all the measurements making up 60.2 imp/min, we have the mean background of the radiometer, equaling 57.2 imp/min.

Some of the data shown in table 4 are presented in fig. 4.

The resultant scattering of measurements can be caused by:

1) statistical scattering of measurements of sea water, as well as of the instrument itself; and

2) instability of the operation of the instrument.

Let us appraise first the <u>instability</u>. The phenomenon was verified several times. The mean scattering of results per 10 min and the calibration value of 0.56 m Curie did not exceed 1°/$_o$.

In order to verify the dependence of the operation of the apparatus on temperature variations, the radiometer was subjected to many hours of cooling in the refrigerator of the "Vityaz'". The temperature variation was 40° (from +34 to -6°). Continuous measurements were made in accordance with the mentioned calibration. The deviation of readings with the decrease of temperature equalled +6°/$_o$.

In addition, it need be mentioned that the temperature of bottom layers of the ocean, beginning with 1000 m, becomes rather constant because the main part of the measurements are carried out at identical temperatures.

Thus, the instability of the operation of radiometer does not exceed 6°/$_o$ (in the direction of decreased values of readings), which corresponds to changes of readings by 3.6 imp/min from 60 imp/min.

<u>Statistical errors of measurements</u>. Assuming that the mean value of the radiometer is 57.2 imp/min and the mean magnitude of activity of sea water (for a given radiometer) is 3 imp/min, we have: /345

$$\frac{\Delta I}{I} = \sqrt{\frac{1+\frac{2I_\phi}{I}}{I\cdot t}} = \sqrt{\frac{1+\frac{114}{3}}{3\cdot 10}} = 1{,}17$$

The statistical error is $\pm$3.5 imp/min. The calculated scattering of instrument readings, determined by statistical measurements, as well as by deficiencies of apparatus, amounts to 10 imp/min.

The overall scattering of readings relative to all measurements corresponds to this magnitude.

It need be noted that if the activity of water doubles, i.e. if the activity is 160 γ'-disintegration/min/ℓ, the scattering of readings would not be less than 17 imp/min.

Thus, the minimum threshold sensitivity of the radiometer is 240 γ'-disintegration/min/ℓ.

At none of the listed oceanographic stations was the scattering of measurement data greater than 10 imp/min; because the measurements were made at various depth levels, we can consider that the level of activity does not exceed 200 disintegration/min/ℓ.

The feasibility of this conclusion (as well as the feasibility of the calculated accuracy of radiometer) is confirmed by experimental data on the calibration of the instrument. The specific activity of K^{42} in $1.1 \cdot 10^{-9}$ Curie/ℓ was accurately recorded by the radiometer (11 imp/min over 66 imp/min during 70 min of measurements), the deviation being 10°/o.

CONCLUSIONS

1. An original deep water gamma-radiometer, which operates automatically, has been created. Its sensitivity threshold is $2 \cdot 10^{-10}$ Curie and it is designed for measuring radioactivity at the maximum depths of oceans.

2. The measurements conducted in the central and northern sectors of the Indian Ocean in 1960 did not indicate an increase of radioactivity to a degree that the natural level would be surpassed more than two to three times.

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* These are the titles as translated by the Russians - original titles were not given.

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